The Influence of Bottom Morphology on Far Field Reflectance

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Grant Number: N000149710011
http://photon.oce.orst.edu/ocean/projects/cobop/cobop.htm

LONG-TERM GOALS

The long term goal of this effort is to determine the influence of the physical structure of the ocean bottom, the sea surface and the Inherent Optical Properties on radiative transfer.

OBJECTIVES

To determine the dependence of the far field optical reflectance on the following parameters:

- Material reflectance (near field reflectance)
- Bottom morphology.
- Source and detector geometries and viewing angle for passive and active sensors.

Inherent Optical Properties, sea surface, and water depth.

APPROACH

- Carry out theoretical analyses of the response of light sources and detectors of Lambertian surfaces with and without morphology. Collaborate with Dr. W. Philpot.
- We are collaborating with Drs. Carder, Wheatcroft, Voss, and Mazel in order to use realistic bottom morphologies and material reflectances measured during the CoBOP experiment.
- We include measured and modeled IOP in the numerical models.
- We make model results available to CoBOP researchers for use in closure studies. Results are prepared for publication.

WORK COMPLETED

During the last 12 months we have carried out further numerical analyses of the near and far field reflectance of a sinusoidal bottom as it relates to the reflectance of a flat bottom with the same material

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**
4. TITLE AND SUBTITLE **The Influence of Bottom Morphology on Far Field Reflectance**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **College of Oceanic and Atmospheric Sciences,,Ocean. Admin. Bldg. 104,Oregon State University,,Corvallis,,OR, 97331**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

(material reflectance). We have further carried models that include surface wave effects, in order to determine the influence of non-flat sea surfaces and ocean bottoms on the horizontal distribution of the internal radiance. This is important as classical radiative transfer assumes that radiance distributions are plane parallel, i.e. the same at a given depth in the ocean.

RESULTS

Measurements of inherent optical properties (IOP) were conducted over bottoms with different substrates by use of a sampling package mounted on and operated by a SCUBA diver. For a description of the sampling package and methods see Zaneveld et al.(2001).Measurements were made with this package during field experiments at Lee Stocking Island, Bahamas. Results of the field work are described in Boss and Zaneveld (2003). The results regarding variability of IOP over substrates can be summarized as follows:

1. The variability in all properties was larger over the reef.
2. Colored Dissolved Material concentration (CDM) was larger over the reef.
3. Attenuation was larger over sand, but its spectral slope was larger over the reef.
4. In most cases, the chlorophyll fluorescence was larger over sand.

In addition, we observed that the mean of a given property was, in general, higher than its median. The slope of the CDM was not significantly different between the two substrates.

The results of vertical variability of IOP can be summarized as follows:

1. The variability in all properties was larger at 10 cm above both reef and sand than further away from the bottom.
2. The CDM concentration was larger at 10 cm above the bottom than further from the bottom. The CDM spectral slope was smaller at 10 cm above both reef and sand.
3. Attenuation increased above the reef, whereas above sand, the change in concentration was not significant.
4. The attenuation spectral slope decreased with increasing distance from both sand and reef substrate.
5. Chlorophyll fluorescence increased away from substrate.

A comparison of transects above shallow seagrass beds and shallow coral reef showed no significant vertical gradients, likely due to mixing by the tidal flows.

The reflectance of the bottom is of importance when interpreting optical data in shallow water. Closure studies of radiative transfer, interpretation of laser line scanner data, lidar, and remote sensing in shallow waters require understanding of the bottom reflectance. In the Coastal Benthic Optical Properties experiment (CoBOP), extensive measurements of the material reflectance (reflectance very close to the bottom) were made. In carrying out closure of the radiative transfer model and observed radiometric and Inherent Optical Properties, what will be needed however is the far field reflectance. The far field reflectance is the bottom reflectance that includes the effect of bottom morphology (such as sand ripples) as well as the material reflectance. We have derived a first order analytical model for the relationship between the material and far field reflectances (Zaneveld and Boss, 2003). This resulted in the simple expression $\rho_{eff} = \rho \langle\cos|\theta_z - \theta_b|\rangle$ for the far field reflectance, ρ_{eff} ,when the material (flat bottom) reflectance is given by ρ. We thus showed that the effective reflectance of the bottom is proportional to the average cosine of the bottom slope. Using a 2-dimensional geometry model without scattering and absorption we show that errors in ignoring the bottom morphology can lead to overestimations of the far field reflectance on the order of 30%. We have thus shown that the

effect of bottom morphology on the far field or effective reflectance can be substantial and cannot be ignored.

We have carried out numerical simulations of the influence of various parameters on the measured upwelling radiance. Below follow examples of the effects of 1) Bottom morphology, 2) surface waves and 3) aperture of the radiance sensor on the measured radiance in the interior of the ocean. The figures show downwelling radiance by means of light rays, and upwelling radiance by means of color.

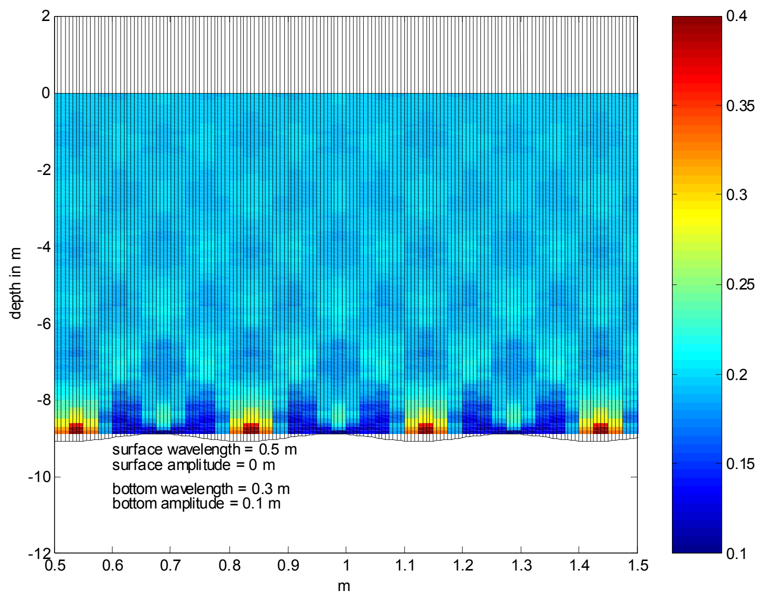

Figure 1. [The upwelling radiance distribution as shown by a color scale, above a sinusoidal bottom. The incident rays are vertical and shown by black lines. We find that the upwelling radiance has a checkerboard pattern. This is due to the finite aperture of the radiance sensor. True radiance would show vertical columns of light and dark above the light and dark bottom areas.]

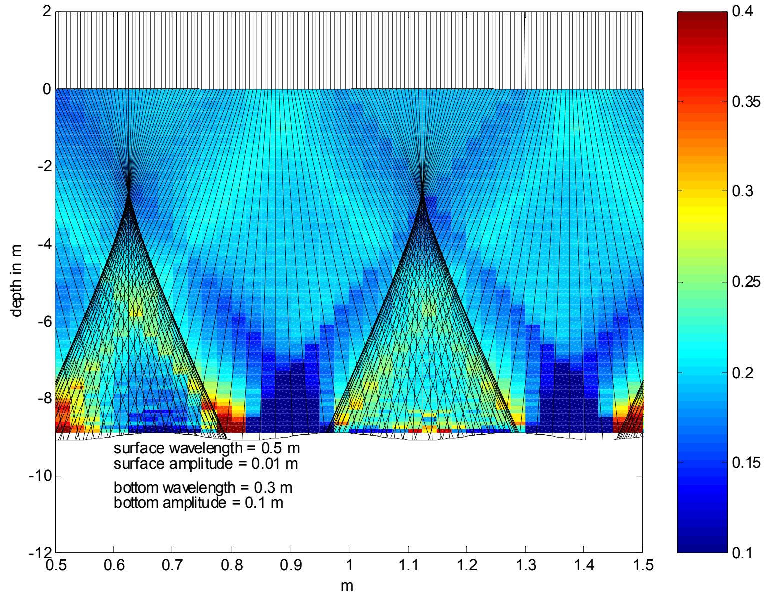

Figure 2.[Same as Figure 1, but with a very small amplitude surface wave added. The checkerboard pattern of upwelling radiance is overwhelmed by wave refraction patterns reflected off the bottom. The refraction pattern is indicated by the black lines, representing rays. Downwelling irradiance is proportional to the horizontal number density of the rays.]

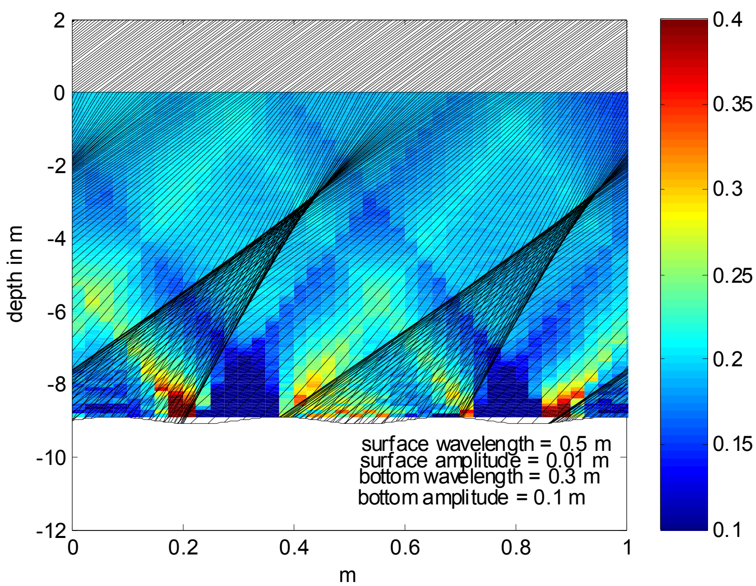

Figure 3. [Same as Figure 2, but with a changed angle of incidence. This does not affect the upwelling radiance distribution very much. The bright spots on the bottom are still due to the rays refracted by the surface wave. The upwelled radiance distribution in the interior is primarily due to the downwelling irradiance distribution on the bottom.]

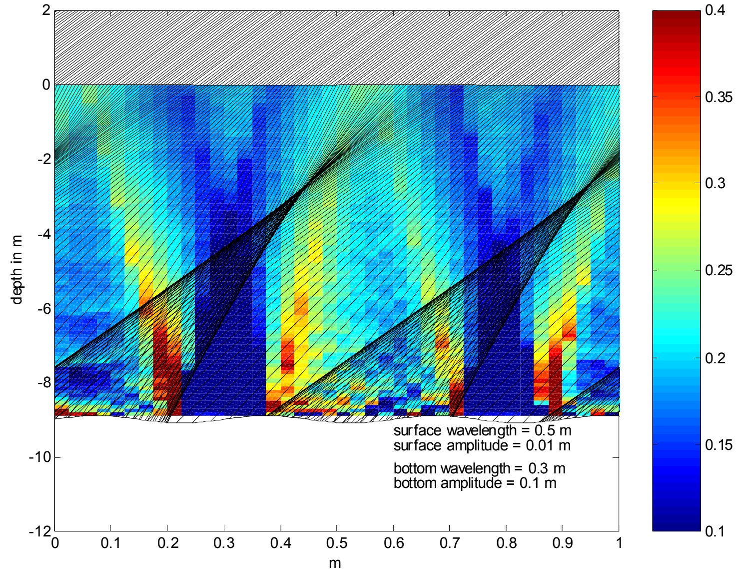

Figure 4.[Same as figure 3, but with the aperture of the radiance sensor decreased from a 3° to a 1° half angle. This changes the measured radiance distribution in the interior. In the limit of 0 °, the radiance maxima are directly above the bright spots. The measurement of radiance is thus significantly influenced by instrument parameters.]

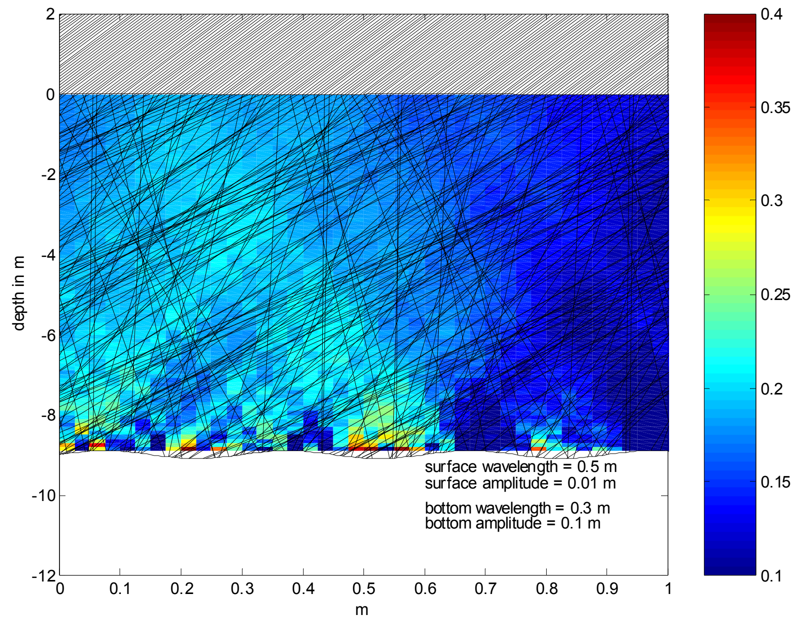

Figure 5. [The same as Figure 4, but with a very small capillary wave (wavelength of 2cm and amplitude of 1mm) added to the sea surface. This scrambles the light rays. There are still bright spots on the bottom, generating increased upwelled radiance locally.]

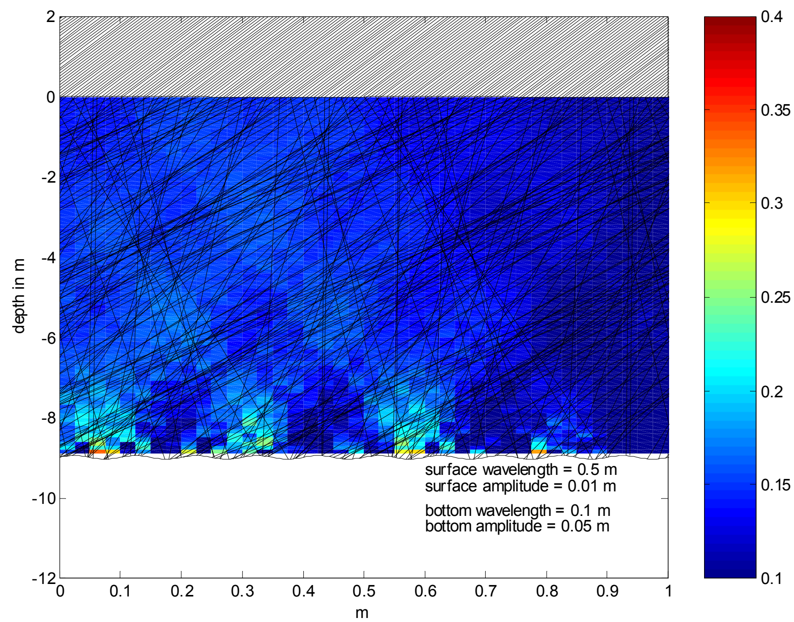

Figure 6. [The same sea surface as Figure 5. but with a different bottom. It is shown that increasing the average slope of the bottom features decreases the upwelling radiance(as shown by the color scale) in the interior, as predicted by the theory that says that the far field reflectance is proportional to the average slope of the bottom.]

IMPACT/APPLICATIONS

Our work will have a significant impact on the interpretation of measured radiance distributions in shallow water, with surface waves and bottom features. Future experimental and theoretical work must take the following into account:
1) For parallel rays the reflectance of a bottom can be simply described as the material reflectance multiplied by the average cosine of the angle of the bottom relative to the incoming rays.
2) For a given bottom morphology the near field reflectance depends on the orientation of the bottom features relative to the light source and the detector. This leads to a complex upwelling radiance distribution.
3) Surface waves scramble the direction of the rays near the bottom so that the upwelling radiance distribution in the interior is dominated by the refraction of the rays at the surface and their reflection off the bottom.
4) Measured radiance distributions depend on the aperture of the radiance detector.

We have provided a method for the measurement of small scale horizontal variability of optical and physical parameters in the benthic environment. We have shown that the gradients in IOP reflect the metabolic processes associated with a coral reef. A major application of this data is to test the plane parallel assumption often used in radiative transfer i.e. it is assumed that IOP do not vary horizontally. Our measurements show that the IOP above coral reefs are not homogeneous horizontally or vertically We have pioneered a new method of measuring pore-water CDOM absorption and physical properties in-situ.

We have shown theoretically that the far field reflectance is equal to the average cosine of the bottom morphology. We have derived a model for the near-field reflectance as a function of the bottom morphology and the material (flat bottom) reflectance.

TRANSITIONS

Our data are being used by Drs. Philpot, Mobley, Reid, Maffione, Zimmerman, and Lesser as inputs into radiative transfer models. We are collaborating with Drs. Philpot and Mobley on radiative transfer theory and models. Dr Burdige uses our pore-water CDOM measurement for comparison with his laboratory measurements of DOC. The data are available on our web site (http://photon.oce.orst.edu/ocean/projects/cobop/cobop.htm). The data have been submitted to Dr. Jeff Smart for inclusion in the ONR Optics data base. Our bottom morphology theory is used in radiative transfer calculations that include bottoms that are not smooth.

RELATED PROJECTS

None

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PUBLICATIONS (supported through this contract)

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